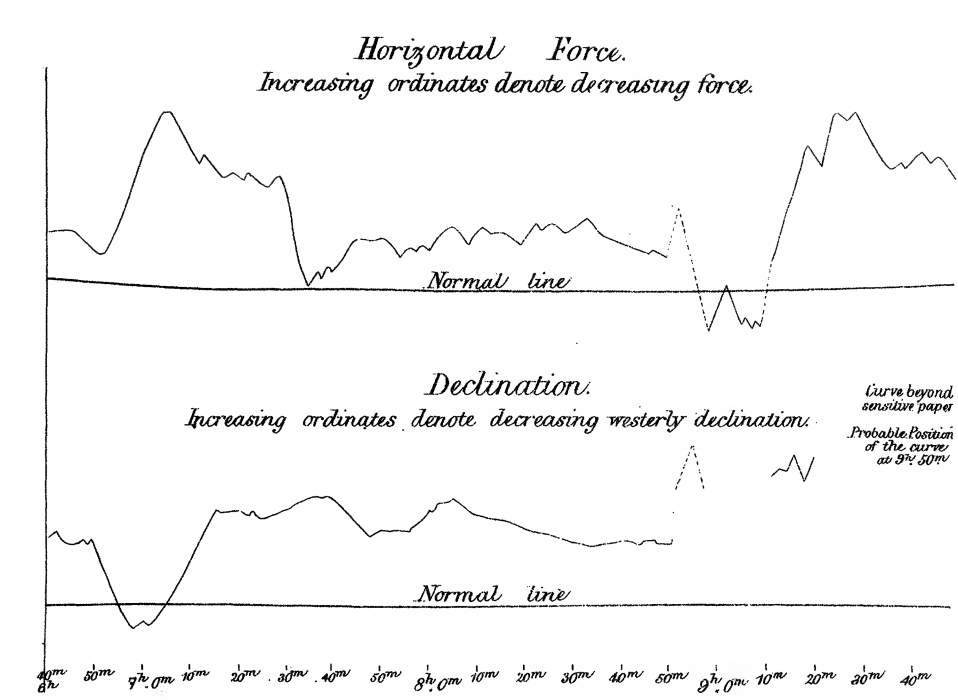
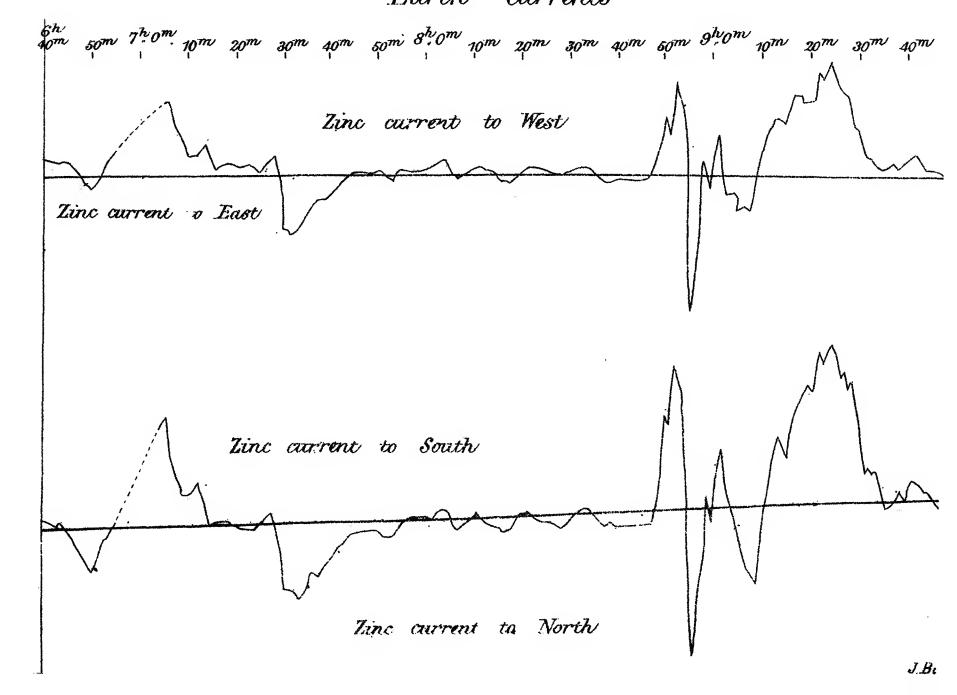

Horizontal Force.
Increasing ordinates denote decreasing force.
Normal line
Declination.
Increasing ordinates denote decreasing westerly declination.
Curve beyond sensitive paper
Probable Position of the curve at 9h 50m
Normal line
6h 40m
50m
7h 0m
10m
20m
30m
40m
50m
8h 0m
10m
20m
30m
40m
50m
9h 0m
10m
20m
30m
40m


Earth Currents
6h 40m
50m
7h 0m
10m
20m
30m
40m
50m
8h 0m
10m
20m
30m
40m
50m
9h 0m
10m
20m
30m
40m
Zinc current to West
Zinc current to East
Zinc current to South
Zinc current to North
J.B.

XIV. "On the Magnetic Disturbance which took place on the 14th of December 1862." By Balfour Stewart, M.A., F.R.S. Received May 19, 1863.

On the 14th of December 1862, a magnetic disturbance occurred about 6 o'clock in the afternoon, and was registered by means of the Kew magnetographs. As usual it was accompanied by an auroral display and by earth-currents, and the latter phenomena were observed at Greenwich by means of a system of telegraphic wires which had recently come into the possession of the Astronomer Royal.

By the kindness of Mr. Airy, the Kew Observatory has been favoured with a copy of the curves which represent the earth-currents collected at Greenwich during the progress of this disturbance; and a comparison of these with the Kew magnetograph curves will form the subject of the following paper. It will, however, first be necessary to state the arrangement adopted at Greenwich. There are two wires proceeding from the Observatory, one ending near Croydon and the other near Dartford (nearly at right angles); and these are well insulated throughout their entire length, and have good earth-connexions at their extremities.

From these, by means of galvanometers, the intensity of earth-currents is recorded for two very favourable directions; and from these again the intensity of those currents which flow in the magnetic meridian, and in a direction perpendicular to it, may be very easily deduced. The standard for direction is the current which flows through the wire of a battery from the zinc pole, and which is called the zinc-current. With this explanation the earth-current diagrams appended to this paper will be quite intelligible; and with regard to the magnetic curves, it is only needful to remark that increasing ordinates denote decreasing declination and decreasing horizontal force, and that the normal lines, which have been furnished through the kindness of General Sabine, denote the position which the curves would have occupied had no disturbance supervened. But before proceeding to compare together the two sets of curves, it will be necessary to advert to a peculiarity of disturbances which enters as an essential element into all such discussions. It has been found by General Sabine that if the disturbances of declination be divided into two categories, easterly and westerly, these obey very different laws

of daily variation, and also that this difference is not of the same description for all stations; so that we are compelled to view a magnetic disturbance as the resultant effect of two disturbances of different character, superimposed upon one another. General Sabine has likewise stated his opinion that this duality of action may perhaps be due to the disturbing force entering the earth at two or more points, one denoting magnetism of a more permanent kind, and the other magnetism of an induced description. A study of the Kew disturbance-curves tends to give confirmation to such an idea; for in these it is seldom found that the whole body of force which produces a disturbance is one which preserves the same type throughout and only varies in intensity. Even if we suppose that this type will vary with the hour of the day, we shall find, if we take disturbances which last for several days, that the type of force at a given hour of the first day is in very many cases different from that during the same hour of the second. When, however, we confine our attention to very abrupt changes of force, we find that the disturbance-type which these display retains more of the same character throughout a disturbance. In order to explain this, we may perhaps suppose that there are two sets of magnetic particles in the earth—one set being of the nature of soft iron, and the other similar to hardened steel. Now only the first of these would be acted on by any very sudden change in the disturbing force, since it would require time in order to influence the second set. We may thus perhaps account for the fact that any very sudden change is of one type, since it only influences one set of particles. Let us now consider what will take place if a disturbance of the same primary nature continues for any length of time. Here the hard-iron particles will also be influenced to an extent compounded of the time and of the average value of the disturbing force during that time. The magnetic needle, therefore, will now be acted on by the joint influence of these two sets of particles, whereas at the beginning of the disturbance it was only acted on by one of them, namely, the soft-iron ones. The type of force will therefore have changed if the hard-iron particles are differently distributed in our globe from the soft-iron ones; and if, instead of two, there are many sets of particles, we shall have a very complicated effect.

Now this duality of disturbing forces must be considered when we

attempt to ascertain the connexion between such forces and earth-currents, since we are not entitled to suppose that one of these two forces is related to earth-currents in precisely the same manner as the other. A small soft-iron force may be comparable to a large hard-iron one as far as an earth-current is concerned; or the reverse may be the case. When, however, there is a very rapid change of disturbing force, since this affects the earth through only one set of particles, we shall by its means be better able to trace the bond of connexion between a single type of magnetic force and the corresponding earth-current. Rapid changes of force are therefore of peculiar value in such an investigation.

Bearing this in mind, let us endeavour to connect together the phenomena of earth-currents and magnetic disturbances by two successive hypotheses, one of which, it would seem, must represent the truth unless there be some new link of connexion between magnetism and electricity with which we are unacquainted. The first hypothesis is that in which earth-currents are supposed to give rise to magnetic disturbances according to the laws by which a current acts upon a magnet. This may be called the theory of direct action.

By the second hypothesis, earth-currents are supposed to be induced, or secondary currents generated in the crust of the earth by those small but rapid changes in terrestrial magnetism which constitute disturbances. This may be called the theory of induced action.

Now, first, on the theory of direct action. Zinc-currents going to the south should correspond with magnetic disturbances decreasing the declination; and zinc-currents going to the east should correspond with an increase of horizontal force; but we find by the diagrams that while on this hypothesis the disturbance of the horizontal-force needle will be tolerably well accounted for by the east and west currents, the same correspondence does not hold between the north and south currents and the declination-disturbance. But I do not think that this circumstance, rightly viewed, tells either in favour of or against the hypothesis. A glance at the earth-current curves will show that the ordinates of the one bear generally a fixed proportion to those of the other, showing us that the total current has flowed backwards and forwards along one line*; and though it is equally apparent, by a glance at the magnetic curves, that the same type of force

* This had been previously observed in other cases by Mr. C. V. Walker.

has not been preserved throughout the disturbance, yet the explanation of the unity of type in the earth-currents may be that these are twisted into a line of motion, owing to the disposition of the conducting strata of the earth's surface, just as a current can only move backwards or forwards along an insulated wire. Indeed a little reflection will show us that earth-currents are not local phenomena; so that if we endeavour to estimate quantitatively their influence on the magnet according to the hypothesis of direct action, we must first extend our field of observation, and obtain their value in other countries besides our own.

But to return to our comparison of curves. We see that for the greater part of the disturbance both the horizontal force and the declination were very much above their normal lines, while on the other hand the currents were frequently crossing their zero lines,—and that both currents were simultaneously and for a long portion of their time very near zero, although during this time the magnetic disturbance was considerable.

Next, with respect to a very abrupt disturbance which commenced about $8^h\ 50^m$, the corresponding earth-current curves are exceedingly powerful, alternately passing and repassing the zero line to nearly the same distance on both sides, while the absolute disturbance of the horizontal force, and probably of the declination, was not very great.

We have thus, in the first place, a very sluggish action of earth-currents, while the magnetic disturbance was considerable, and in the next place a very violent action of the former when the absolute disturbing force was by no means excessive; and we may add that at $9^h\ 50^m$ both earth-currents were near zero, while both elements of the earth's magnetism were much disturbed.

For all these reasons this comparison of the curves is unfavourable to the hypothesis of direct action.

Let us now consider the other hypothesis, or that of induced action, and we shall find the following points in its favour.

1st. That in this disturbance, for at least one hour, both elements of the earth's magnetic force remained at a considerable distance from their normals, and that during this time the earth-currents observed were exceedingly small. Now, on the hypothesis of induced action, the earth-current effect depends not on the absolute value of the disturbing force, but on its rate of change; and if during this

period we examine the horizontal-force curve, we shall find the abruptness of change not so great as in those cases where greater earth-currents were produced, while in the declination-curve the abruptness of change during this period is exceedingly small.

2nd. A reference to the diagrams will show us that in general the most abrupt magnetic disturbances are those which are accompanied by the greatest earth-currents, and that in particular a very abrupt disturbance, which took place about $8^h\,50^m$, was accompanied by very strong earth-currents, alternately positive and negative, those of the one name being nearly as powerful as those of the other, while on the other hand the corresponding magnetic disturbances were on an average decidedly on one side of the normal lines.

On the other hand, the following fact seems at first to tell against the theory of induction. An inspection of the curves will show that we have currents remaining on one side of the zero-line for some length of time, during which the magnetic disturbances have nevertheless changed in both directions. When, however, we reflect on this circumstance, we are led to see that since we have two sets of disturbances taking place simultaneously, so we must also have two sets of earth-currents. Now one of these disturbances, which we may perhaps call the soft-iron one, reproduces those small and rapid changes which take place in the primary force, while on the other hand the hard-iron disturbance averages these small changes and presents us with a disturbance-wave of long period. Precisely, then, as in the magnetic curves we have waves of short period superimposed upon waves of long period, so will it be in the earth-current curves. Those currents due to the soft-iron disturbances will be superimposed upon those due to the hard-iron ones, with this difference, that we are not entitled to assume that the proportion in intensity between the two simultaneous earth-currents must be precisely that which exists between the rates of change of the two corresponding simultaneous disturbances. It will be apparent that this feature of duality ought also to be presented by the aurora; and here it is well known that we have at least two phenomena, one of a more fitful and the other of a more permanent character, namely, the streamers and the auroral arch. We may suppose the first of these phenomena to correspond to the soft-iron, and the second to the hard-iron disturbances. Indeed it is questionable whether the different

varieties of auroræ are confined to these two; for General Sabine has informed me that he himself, along with the late Sir Edward Parry, observed at Lerwick in the Shetland Isles in 1818, at the same instant, two auroral arches crossing one another at an angle. But, be this as it may, when we reflect that there are many kinds of particles in our earth, some of which may be affected more rapidly than others by a primary magnetic force, we shall cease to wonder that the phenomena presented are of a complicated description.

All these considerations have induced me to think that it is lost labour to attempt a quantitative comparison when our observation of the magnetic disturbances and their corresponding earth-currents is confined to one locality; and it will be seen from this paper, that while endeavouring to uphold the hypothesis of induced action, I have done so by a comparison of a general and qualitative rather than by one of a quantitative nature.

XV. "Further Observations in favour of the View that Nerve-fibres never end in Voluntary Muscle." By Lionel S. Beale, M.B., F.R.S., Fellow of the Royal College of Physicians, Professor of Physiology and of General and Morbid Anatomy in King's College, London; Physician to King's College Hospital, &c. Received June 5, 1863.

Few anatomical inquiries of late years have excited more interest than the present one. Since my paper published in the 'Philosophical Transactions' for the year 1860, several memoirs have appeared in Germany. In my paper just published in the last volume of the 'Transactions,' I have replied to the statements of Kühne and Kölliker, but I had not succeeded in actually tracing the very fine nucleated fibres I had demonstrated from one undoubted nerve-trunk to another. As a *demonstration*, therefore, my conclusions *were defective*, though the only explanation to be offered of facts I had observed was that included in the view I propounded in my first paper. The question between my opponents and myself upon this matter is not one of interpretation, but a question of simple fact. I assert that the fine nerve-fibres can be followed much further than the point where Kühne and Kölliker maintain the ends or *termina-*